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Review

Effect of dietary linseed on the nutritional value and quality of pork and pork products: Systematic review and meta-analysis

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ABSTRACT

Nutritional quality of pork is a significant factor for consumers' health. Feeding n-3 PUFA to pigs, using linseed, improves pork nutritional quality. A meta-analysis involving 1006 pigs reported in 24 publications was carried out to assess the effects of dietary linseed on alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA) and docosahexaenoic acid (DHA) content in muscle and adipose tissue. Data showed positive effects of n-3 PUFA on muscle fatty acid composition: ALA + 137%, EPA + 188%, DPA + 51% and DHA + 12%. Same results were observed in adipose tissue: ALA + 297%, EPA + 149%, DPA + 88% and DHA + 18%. A positive correlation between dietary treatment and ALA and EPA content in muscle ($P < 0.001$) and adipose tissue ($P = 0.036$) was observed. A significant association between DPA ($P = 0.04$) and DHA ($P = 0.011$) and live weight in muscle was observed. Feeding linseed to pig improves the nutritional pork quality, raising the n-3 PUFA content in muscle and adipose tissue.

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1. Introduction

In recent years, consumer interest in the relationship between diet and health has increased the demand for functional foods. Omega-3 fatty acids are recognised to be functional components that may reduce

Abbreviations: ALA, alpha-linolenic acid (18:3n-3); ARA, arachidonic acid (20:4n-6); CM, castrated males; CMF, both genders; DHA, docosahexaenoic acid (C22:6n-3); DPA, docosapentaenoic acid (22:5n-3); E, energy; EPA, eicosapentaenoic acid (C20:5n-3); F, females; IMF, intramuscular fat; LA, linoleic acid (18:2n-6); LC, long chain; LTL, *Longissimus thoracis et lumborum*; LW, live weight; TBARS, thiobarbituric acid reactive substances.

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the incidence of cardiovascular disease (Beilin & Mori, 2003; Connor, 2000; Kris-Etherton, Harris, & Appel, 2002).

It has been assumed that the physiological requirement for long chain (LC) n-3 PUFA can be satisfied by the consumption of plant foods (such as linseeds, walnuts, soybean and canola oils), containing their precursor alpha-linolenic acid (ALA). Conversion of ALA into eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in humans is low (Portolesi, Powell, & Gibson, 2007), and the conversion to DHA is better in infants than in adults, as also recently reported in pigs (Brenna, Salem, Sinclair, & Cunnane, 2009; De Quelen, Boudry, & Mourot, 2010). In pigs, it has been observed (Kloareg, Noblet, & Van Milgen, 2007) that approximately one-third of the supplied n-3 that was deposited resulted from the conversion of ALA to EPA and DHA.

Currently, authorities (EFSA, 2012; FAO/WHO 2008) recommend that the macronutrient distribution range in adults include the consumption of 20% to 35% of total energy (E) from fat although one authority suggest that it is possible to increase the amount till 40% (AFSSA, 2010), with a maximum of 10% of E from SFA and up to 6–11% of E from PUFA. The intake of n-3 fatty acids should be 0.5–2% of E and the intake of n-6 fatty acids should be 2.5–9% of E. Recommendations concerning the n-6/n-3 ratio suggest a value between 5:1 and 10:1. Nutritionists have expressed concern that the typical Western diet provides too much n-6 and not enough n-3 PUFA (Givens & Gibbs, 2008). One way to increase the intake of n-3 PUFA, without changing the consumers' nutritional behaviour, would be to fortify traditional foods such as meat and meat products with n-3 PUFA. Indeed meat is one of the major sources of fat in the diet with an average European per capita consumption of around 98 kg (Llorens Abando & Martinez Palou, 2006). Meat fat contains a high amount of SFA associated with some modern diseases (Wood et al., 2003).

Feeding n-3 PUFA to pigs using linseed could improve the nutritional quality of pork, but may adversely affect its sensory qualities due to the susceptibility of n-3 PUFA to oxidation (Lyberg, Fasoli, & Adlercreutz, 2005).

The aim of this work was to identify and summarise the main effects or the effect orientation of dietary enrichment with n-3 PUFA using linseed and to review works showing the effect of increasing PUFA n-3 content in pig tissues on meat quality. Considering the great amount of literature that investigates the effects of dietary linseed on pork quality traits and the high results variability, due to the different experimental conditions, there is a need to obtain a statistical synthesis. A meta-analysis was conducted in order to establish the real effect of the orientation of linseed dietary exposure on nutritional meat quality parameters from a set of comparable studies. Further, because few data are available on physical and sensory characteristics of meat quality of pork fed linseed, a critical review was performed.

2. Materials and methods

Animal Care and Use Committee approval was not required for this study because the data were obtained from an existing database.

2.1. Literature search

A systemic literature search was carried out by search of journals, book articles and abstracts from CAB Abstracts (ISI) to identify articles published between January 1975 and April 2013. The structured strategy included the following keywords applied as follows: “pork” OR “pig” AND “n-3 PUFA” OR “Omega 3” OR “linseed” OR “flaxseed” AND “fatty acids”. A manual review of the reference list of the selected articles was conducted to identify additional articles for possible inclusion. Additional studies were identified from the reference lists of retrieved articles. The literature search focused exclusively on articles published in peer-reviewed journals for the methodological accuracy of the studies.

Two independent reviewers, evaluated the eligibility of each article. The reviewers were blinded to author, institution, and journal of publication. Articles were excluded based on abstract review only if both reviewers independently believed the inclusion criteria were not met. Otherwise, all the remaining studies were assessed using the complete papers. Any disagreements between the two reviewers were resolved by a third reviewer.

2.2. Study selection

To be included in the review the studies needed to satisfy the following criteria: (1) data collected from January 1975 up to April 2013; (2) English, French or Italian language; (3) study carried out in crossbred pigs from about 25 to 160 kg of live weight (LW); (4) linseed supplemented diet; (5) study assessed both control and linseed supplemented diets using isoenergetic and isoproteic diets; (6) study reported fatty acid composition of *Longissimus thoracis et lumborum* (LTL) muscle and/or adipose tissue. Our principal aim was to evaluate the effect of linseed dietary treatment on meat quality parameters, referring in particular to fatty acid composition of muscle and adipose tissue. For this reason experimental trials, involving different genetic types, body weight and length of linseed supplementation, in which meat quality parameters were evaluated, were selected. Considering the restricted amount of trials we include in the meta analysis animals with average initial weight of 49.4 kg (25 to 85 kg LW) and average final weight of 98.4 kg (from 50 kg to 160 kg LW). Dietary linseed supplementation of included studies ranged from 30 to 103 days. Growth performances (average daily gain, average daily feed intake) were not evaluated due to the inadequate number of results. Not one of the examined studies explicitly reported blinded analyses of the results and nine studies were classified as randomised because they reported that the trial involved random assignment of animals to treatment groups. Some studies reported dietary comparisons were not relevant to this article, or if there were more than one comparison group, only the results addressing the objectives of this article were extracted. The outcomes evaluated were the fatty acid composition of LTL muscle and subcutaneous adipose tissue.

The data on ALA, EPA DPA and DHA content in intramuscular fat (IMF) and adipose tissue were subjected to a meta-analysis. The lipid extraction methods were not taken into account for the restricted results available. Moreover, considering the limited number of data we decided to include linseed oil and extruded linseed, with awareness of the different fat digestibility. In fact, fat digestibility of ground linseed was considerably lower than after extrusion (51% vs. 81% and 90% for two different extrusion procedures) (Noblet, Jaguelin-Peyraud, Quemeneur, & Chesneau, 2008). In addition, linseed oil had a higher digestibility in pigs (92.6% apparent ileal digestibility) than ground linseed but comparable to extruded linseed (Duran-Montgé, Lizardo, Torrallardona, & Esteve-Garcia, 2007).

2.3. Data extraction

A database was created, including detailed description of each reference: author's name, publication year, animals used (gender, breed, weight), housing condition (group size), design details (randomisation and blinding), control and experimental diets (including description of n-3 fatty acids), source and dose of linseed, duration of feeding, tissues sampling, statistical analyses (mean value, standard deviation/standard error and P value) and fatty acid composition of *Longissimus thoracis et lumborum* (LTL) muscle and/or adipose tissue. Lipid extraction method was not taken in account.

2.4. Statistical analysis

The inputs for meta-analysis were statistical analysis results reported in literature: means or difference in means, standard error/standard deviation and P-value. The effect sizes were calculated using Hedges' *g* approach. The random-effect model was used to determine the overall

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